

Final Report for Period: 01/2009 - 12/2009**Submitted on:** 12/21/2009**Principal Investigator:** Fujimoto, Richard M.**Award ID:** 0540160**Organization:** GA Tech Res Corp - GIT**Submitted By:**

Fujimoto, Richard - Principal Investigator

Title:

DDDAS-TMRP: Dynamic, Simulation-Based Management of Surface Transportation Systems

Project Participants**Senior Personnel****Name:** Fujimoto, Richard**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Leonard, John**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Guensler, Randall**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Schwan, Karsten**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Hunter, Michael**Worked for more than 160 Hours:** Yes**Contribution to Project:****Post-doc****Graduate Student****Name:** Palekar, Mahesh**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Mahesh did the initial work in developing the ad hoc distributed simulation algorithm and software.

Name: Sirichoke, Jason**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Jason continued the work Mahesh began on the ad hoc simulation work, after Mahesh graduated, by continuing development of the software, developing refinements to the simulation model, and performing experiments.

Name: Seshasayee, Balasubramanian**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Bala has been developing the middleware algorithms and software for data dissemination to support distributed ad hoc simulations.

Name: Kim, Hoe-Kyoung

Worked for more than 160 Hours: Yes

Contribution to Project:

Hoe-Kyoung has been working on the data collection and analysis part of the project, and integrating this data with the VISSIM simulation.

Name: Suh, Wonho

Worked for more than 160 Hours: Yes

Contribution to Project:

Wonho has been developing the VISSIM simulation for Atlanta and adapting it for use in the ad hoc simulation paradigm.

Name: Huang, Ya-Lin

Worked for more than 160 Hours: Yes

Contribution to Project:

Ya-Lin conducted research concerning statistical analysis of ad hoc simulation outputs.

Name: Hagler, Edward

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Name: Young, Javier

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Name: Thompson, Eric

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: North Carolina A&T

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Watts, Jewel

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: North Carolina A&T

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Baker, Brandon

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: North Carolina A&T

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Harvey, Toyon

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: North Carolina A&T

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Jones, Kendra

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: North Carolina A&T

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Stensland, Benjamin

Worked for more than 160 Hours: Yes

Contribution to Project:

Research concerning testbed implementation and experimentation.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2008

REU Funding: REU supplement

Name: Robinson, Jason

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked on transportation system simulation development and configuration

Years of schooling completed: Sophomore

Home Institution: Other than Research Site
Home Institution if Other: Stanford University
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2007
REU Funding: REU site award

Organizational Partners

Georgia Department of Transportation

A follow up project in applying the DDDAS concept to a pilot study in Atlanta Georgia was approved by GDOT.

Apalachee High School

Apalachee participated in our K-12 curriculum outreach effort by incorporating transportation simulations in high school courses.

Other Collaborators or Contacts

We have briefed the U.S. Army Joint Forces Command (JFCOM) concerning the project, and have provided materials concerning the project to that office. A white paper proposing a specific collaboration with JFCOM for technology transition was prepared, but funding limitations precluded implementation of the proposed project.

We were also contacted by Toyota InfoTechnology Center, U.S.A., Inc. regarding their interest in our publications on this project. Building on this project we analyzed scenarios of probe vehicle information accuracy for freeway and arterial environments for Toyota. For the freeway analysis, we compared field deployed smart vehicle measurements with an ATMS video detection system. For the arterial analysis, we performed a simulation study of the use of probe vehicles to estimate the current traffic state. Toyota provided funding for this effort.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Research and Education Activities

Ad Hoc Distributed Simulations

Consider a collection of in-vehicle simulations that are interconnected via wireless links and (possibly) wired network infrastructure. Individually, each simulation only models a portion of the traffic network ? that which is of immediate interest to the ?owner? of the simulator. Collectively, these simulations could be used to create a kind of distributed simulation system with the ability to make forecasts concerning the entire transportation infrastructure as a whole. One can envision combining in-vehicle simulators with simulations running within the roadside infrastructure, e.g., within traffic signal controller cabinets, simulations combining sub-regions of the transportation network, and simulations running in traffic management centers to create a large-scale model of a city?s transportation system.

We term a collection of autonomous, interacting simulations tied together in this fashion an ad hoc distributed simulation. Like a conventional distributed simulation, each simulator within an ad hoc distributed simulation models a portion of the overall system, and simulators exchange time stamped state information to collectively create a model of the overall system. However, in a conventional distributed simulation the system being modeled is designed in a top-down fashion. Specifically, the system is neatly partitioned into non-overlapping elements, e.g., geographic regions, and a logical process is assigned to model each element. By contrast, an ad hoc distributed simulation is created in a bottom-up fashion with no overarching intelligence governing the partitioning and mapping of the system to logical processes. Rather, the distributed simulation is constructed in an ?ad hoc? fashion, in much the same way an arbitrary collection of mobile radios join together to form an ad hoc wireless network. The elements of the physical system modeled by different simulators in an ad hoc distributed simulation may overlap, leading to possibly many duplicate models of portions of the system. Other parts of the system may not be modeled at all. For example, an in-vehicle transportation simulator may be only modeling the portion of the road network along the vehicle?s intended path to reach its destination. Thus, ad hoc distributed simulations differ in important fundamental ways from conventional distributed simulations.

An ad hoc transportation simulation based on a cellular automata model was developed for our initial investigations. The simulation consists of agents modeling vehicles, traffic signal controllers and traffic lights. The simulation operates in a timestep fashion. At every timestep, each agent decides what operation to perform next based on its own characteristics and the state of the system at the end of previous interval. Each vehicle agent includes characteristics such as origin, destination, maximum speed of the vehicle, and driver characteristics such as aggressiveness. Each vehicle has complete knowledge of the road topography around it.

While the cellular automata simulation model allowed for the development of an understanding of the behavior of the ad hoc distributed approach it is desirable that future experimentation be conducted with a significantly more detailed, robust transportation simulation model. Further, the ability to adapt existing commercial simulation software for use in ad hoc distributed simulations would significantly improve the likelihood that the technology would be used. An initial investigation into implementing the ad hoc strategy using the off-the-shelf transportation simulation model VISSIM was conducted. VISSIM is widely used by private firms and public agencies for transportation system analysis. VISSIM is a discrete, stochastic, time step based microscopic simulation model developed to model urban traffic (freeway and arterial) and public transit operations. The model is capable of simulating a diverse set transportation network features, such as facility types, traffic control mechanism, vehicle and driver types, etc. Individual vehicles are modeled in VISSIM using a psycho-physical driver behavior model developed by Wiedemann. The underlying concept of the model is the assumption that a driver can be in one of four driving modes: free driving, approaching, following, or braking. VISSIM version 4.10 was utilized for this investigation.

Real-Time Dynamic Data Analysis

The precision of the real-time data varies depending on the level of data aggregation. For example, minute-by-minute data are more precise than hourly average data. We examined the creation of an accurate estimate of the evolving state of a transportation system using real-time roadway data aggregated at various update intervals.

Using the VISSIM model described in the previous section, a simulation of the transportation network in the vicinity of the Georgia Institute of Technology in Atlanta, Georgia was utilized to represent the real world, with flow data from the Georgia Tech model provided to a smaller simulation of two intersections within the network. The "real-world" flow data (i.e. flow data measured from the large scale Georgia Tech model) was aggregated in different intervals and used to dynamically drive the two-intersection model. The desire of this study was to explore how well the small-scale simulation model is able to reflect the real world scenario when fed data at different aggregation levels. This work explored congested and non-congested traffic demand at data five different aggregation time intervals: 1 sec., 10 sec., 30 sec., 60 sec., and 300 sec.

Data Dissemination

The proposed DDDAS system relies on mobile, wireless ad hoc networks to interconnect sensors, simulations, and servers. The initial experiments were conducted over a local area network, and thus do not take into account the performance of the wireless network. However, the performance of the network infrastructure can play an important role in determining the overall effectiveness of the ad hoc distributed simulation approach. Thus, a separate effort has been devoted to examining the question of the impact of network performance on the results produced by the ad hoc distributed simulation.

Clearly, a single hop wireless link between the vehicles and servers severely limits the wireless coverage area, motivating the use of a multihop network. However, standard routing protocols designed for end-to-end communication in mobile ad hoc networks cause each node to maintain the state of their neighboring nodes, for efficient routing decisions. Such a solution does not scale to vehicular networks, where the nodes are highly mobile, and route maintenance becomes expensive. Other routing protocols such as those discussed in the literature attempt to address this problem using flooding or optimistic forwarding techniques.

Vehicle ad hoc network (VANET) data dissemination protocols are typically designed to address data sharing among the vehicles, and related applications such as multimedia, control data, etc. Distributed simulations, however, define a different data transfer model, and consequently, the solutions designed for data sharing applications may not perform well when transposed to the demands of simulations. Additionally, data transfers in VANETs is inherently unreliable, and drops and delays in message delivery can be highly dependent on factors such as traffic density and wireless activity, thus having a strong impact on the simulation itself.

To address this challenge, a data dissemination framework for addressing the routing demands of a distributed simulation in the VANET environment has been developed. Our framework uses a combination of geographic routing and controlled flooding to deliver messages, with no organization enforced among the vehicles. The design parameters of the framework are currently under study in order to assess how this impacts the overall accuracy and reliability of simulation results.

Compared to traditional sequential simulations, ad hoc distributed simulations distribute simulation tasks over clients, who later on send to the server data that are required by other clients. Since multiple clients may simulate a common portion of the application, the server would receive various values with respect to a specific datum. When a client request a value of the datum, the server has to aggregate those values and send it to the client. Different methods of aggregating those values can lead to different simulation results. We refer this issue as the updates

aggregation issue.

Due to the distributed nature of ad hoc distributed simulations, more input parameters are required. For example, if a transportation network is divided into two parts at a specific road segment, the road, which was an internal road, becomes an outgoing road to one sub-network and an incoming road to the other sub-network. For the incoming road, input parameters are required for simulating the corresponding sub-network. This can be problematic because we do not want to manipulate the simulation output by setting the input parameters to inappropriate values. In ad hoc distributed simulations, this problem is solved by requesting the server to provide the value. Nevertheless, what the server can provide, or say what the clients can send to the server, is the high level abstraction of the actual data. To use this as a value for an input parameter, we need to apply some methods to disaggregate the value. We refer this issue as the input distribution problem.

Queueing Network Models

Ad hoc distributed simulations are a new approach compared to classic distributed simulation. Each simulation models a section of a larger physical system, contributing its predictions to construct an overall prediction of the future state of the system. Initially developed for transportation simulation, we believe the ad hoc distributed simulation paradigm is applicable to a variety of other application domains. To test this hypothesis, we embarked on a study of ad hoc distributed simulations of queueing networks. An empirical investigation was conducted to test this hypothesis.

Field Studies

An ad hoc distributed simulation testbed was developed in order to test the viability of this approach under realistic test conditions. The initial deployment of the testbed focuses on a section of a roadway spanning approximately four city blocks in the vicinity of the Georgia Tech campus. The road network includes four signalized intersections and WiFi communication throughout the entire area, and provided linkages to a wired communications infrastructure. A detailed microscopic simulation model of this area was developed using VISSIM, a commercial transportation simulation package. Live traffic through the area covered by the testbed was measured and used to drive the transportation simulation.

In order to establish the wireless communications performance within the testbed, a field study was conducted under real-world conditions. Message latency was measured in order to assess delays and losses that could be expected in an actual deployment of the ad hoc approach. Studies were conducted to determine if regional models could adequately represent vehicle travel times when presented with observed vehicle flow rates. Measured traffic flows provided inputs to the simulation model and results were compared to observed vehicle travel times for everyday traffic utilizing the area covered by the testbed.

Findings: (See PDF version submitted by PI at the end of the report)

Project Findings

Ad Hoc Distributed Simulations

Ad hoc distributed simulations are on-line simulation programs, meaning they are able to capture the current state of the system through measurement, and then execute forward as rapidly as possible to project a future state of the system. By assumption, each of the simulators making up the distributed simulation can simulate some portion of the system faster than real time.

Ad hoc distributed simulations require a synchronization protocol to coordinate interactions among other simulations. For this purpose we have developed an optimistic (rollback-based) synchronization protocol designed for use in these systems. Each in-vehicle simulator utilizes information concerning traffic conditions and predictions of future system states (e.g., road flow rates) to complete its simulation. If this information changes beyond certain parameterized limits, the simulator rolls back, and corrects its previously computed results. Based on this protocol, a prototype ad hoc distributed simulation system has been developed using both a custom-developed cellular automata traffic simulator as well as a commercial simulation tool called VISSIM.

We have conducted initial experiments in the management of 20 client simulations over a 10 intersection corridor. Under steady state conditions, the distributed simulation client provided a system representation similar to that of replicated trials. When a spike in the traffic flow was introduced into the network, the distributed clients again successfully modeled the traffic flows; however there was a short delay (up to approximately four minutes) in the upstream client transmitting the increased flows to the downstream clients. The simulation used was a cellular automata model specifically developed for these experiments. Experimentation on more complex transportation systems will require the use of a more robust transportation simulation. Thus, an initial experiment was conducted using the off-the-shelf transportation microscopic simulation VISSIM. In this experiment the roll back algorithm was successfully implemented in VISSIM.

Real-Time Dynamic Data Analysis

For the non-congested conditions, there existed minor differences in the average value of the considered performance metrics (arrival time and delay) and the performance metric difference values for the tested scenarios. However, there was a clear trend of increasing the root mean square error (RMSE) as the aggregation interval increased. Varying the upstream origin of the arrival streams also tended to influence the RMSE values more than the average values. From these results it can be seen that under non-congested conditions, the average of performance metrics alone are likely not good indicators of the ability of a data driven simulation to reflect real world operations. Measures of variation such as RMSE should also be considered.

Unlike the non-congested conditions, the average values of the performance metrics in congested conditions were considerably different for the large real world simulation than the local simulation. The RMSE values also were significantly greater than those in the non-congested scenarios. There is also not a clear trend of the local simulation providing an improved reflection of the large simulation when given the smaller aggregation intervals. For the tested scenarios, the impact of congestion dominated the impact of a selected aggregation interval and upstream arrival pattern. The use of outflow constraints significantly improved the local model performance. These constraints helped capture the impact on the local simulation of congestion that occurs outside the local model boundaries. Where the boundaries of the congested region fall outside of the local simulation it becomes readily apparent that both the inflow and outflow parameters of the simulation must be dynamically driven to achieve a reasonable reflection of the real world conditions.

In the deployment of in-vehicle simulations these experiments highlight the need for realistic field measured inflow and outflow data streams, which are not currently widely available. However, as sensor technologies have advanced, the amount of available real-time field data is increasing dramatically. The quantity of available real-time data is expected to continue to climb at an ever-increasing rate. This tidal wave of real-time data opens the floodgates to potential data driven transportation applications. This effort has begun to examine some of the innumerable potential uses of this data.

Queueing Network Models

An ad hoc distributed simulation requires an underlying framework to synchronize the individual simulators that it is using in the simulation. Since these simulators are often designed independently beforehand as single process simulations, the framework must interact with them through a specified interface. It can be assumed that this interface is sufficient to allow the framework to interact with the simulator and access its internal state. Certain synchronization mechanisms must be provided to ensure correctness.

Initial experiments use a basic queueing simulation running on a generic ad hoc framework with 40 clients distributed over a 10x10 uniform torus network. Under steady state conditions at various population levels, the ad hoc simulation produces comparable results to replicated trials for several individual server metrics. The notable exception to this is predicting the average wait time at the server. Since the wait time is more sensitive to small changes at higher populations and is dependent on the behavior neighboring servers, this suggests that a more comprehensive global object state and rollback function is necessary. This illustrates the point that using the ad hoc framework does not automatically guarantee accurate simulation results. The framework itself is merely a tool for constructing a simulation. The quality of the simulation depends on whether it is used correctly and effectively.

Future work is needed to continue to explore the viability of the ad hoc distributed simulation framework. Scalability becomes a concern when running complex ad hoc simulations featuring possibly hundreds of clients with limitations on memory, bandwidth and computation time. Different commercial simulation packages should be tested with the proposed framework to examine whether it is sufficiently general to be used with any simulation while providing the facilities to help ensure correctness. Eventually as the ad hoc distributed simulation concept matures, the framework will have to be adjusted to compensate for new features such as real-time data sources and a true ad hoc synchronization protocol.

Field Studies

A series of experiments were conducted to examine wireless communications performance and on-line simulation accuracy in the testbed area. These experiments show that on-line traffic simulations can reasonably predict travel times for vehicles in the region covered by the testbed. VISSIM was shown to produce reasonable travel time estimations when utilizing obtained flow rates from the modeled region. Communications experiments revealed high variability in message latencies, suggesting that an on-line simulation must be robust to such variation in the performance of the communication structure, even under 'normal' operating conditions. The technical challenges regarding VISSIM and space-time memory integration were proven surmountable during this implementation.

As with all simulation programs, predictive capability is dependent upon model fit and input scope. Not surprisingly, the simulation was accurate when assumed flow rates were similar to actual conditions. Presumably, greater accuracy could have been obtained if all entering flow rates were observed and utilized during the period. In addition, the incorporation of real time signal control parameters will likely greatly enhance the simulations ability to reflect field conditions. Another result was establishing the effectiveness of the space-time memory in that flow rates were shown to be an appropriate aggregate representation of regional state.

Training and Development:

The project involves multidisciplinary research including graduate students and faculty from the College of Computing and the School of Civil and Environmental Engineering. These students have worked closely together in research activities concerning the modeling and simulation of transportation systems.

Aspects of the project are being incorporated in a course on modeling and simulation that includes students from computing, science, and engineering backgrounds. Course projects are planned including concepts such as ad hoc distributed simulation of transportation systems.

Outreach Activities:

We have participated in outreach activities with the U.S. Army Joint Forces Command to transition project results for use in military logistics operations.

We participated in a poster session that was open to the public to highlight the opening of a new building at Georgia Tech (the Klaus Advanced Computing Building).

We hosted a minority undergraduate student and a high school student as interns during the summer of 2007. Further, we hosted two minority high school teachers and assisted them in developing course materials in transportation simulations for a minority high school in the Atlanta metropolitan area.

The project hosted eight undergraduate and masters student interns during the summer of 2008, including seven African American students (three female). These students work on testbed implementation and experimentation during their summer internship.

We worked with three high school teachers from Apalachee High School who developed curriculum modules using transportation simulation software for use in classes in mathematics (statistics), environmental science, and engineering.

Journal Publications

R. M. Fujimoto, M. Hunter, J. Sirichoke, M. Palekar, H.-K. Kim, W. Suh, "Ad Hoc Distributed Simulations", Principles of Advanced and Distributed Simulation, p. 15, vol. 1, (2007). Published,

M. P. Hunter, R. M. Fujimoto, W. Suh, H. K. Kim,, "An Investigation of Real-Time Dynamic Data Driven Transportation Simulation", Proceedings of the Winter Simulation Conference, p. 1414, vol. , (2006). Published,

B. Petit, M. Ammar, R. M. Fujimoto, "Protocols for Roadside-to-Roadside Data Relaying over Vehicular Networks", IEEE Wireless Communications and Networking Conference, p. 294, vol. 1, (2006). Published,

R. M. Fujimoto, R. Guensler, M. Hunter, H.-K. Kim, J. Lee, J. Leonard III, M. Palekar, K. Schwan, and B. Seshasayee, "Dynamic Data Driven Application Simulation of Surface Transportation Systems", Workshop on Dynamic Data Driven Application Simulations, p. 425, vol. , (2006). Published,

R. M. Fujimoto, R. Guensler, M. Hunter, K. Schwan, H.-K. Kim, B. Seshasayee, J. Sirichoke, W. Suh, "Ad Hoc Distributed Simulation of Surface Transportation Systems", Workshop on Dynamic Data Driven Application Simulations, p. 1050, vol. 1, (2007). Published, May 2007

B. Seshasayee, M. Hunter, R. M. Fujimoto, R. Guensler, K. Schwan, H.-K. Kim, J. Sirichoke, W. Suh, "On the Resilience of Ad Hoc Distributed Simulation of Surface Transportation Systems with Unreliable Communications", Journal of Algorithms and Computational Technology, p. , vol. , (2009). Accepted,

M. Hunter, H.-K. Kim, W. Suh, R. M. Fujimoto, J. Sirichoke, and M. Palekar, "Ad Hoc Distributed Dynamic Data-Driven Simulations of Surface Transportation Systems", Transactions of the Society for Modeling and Simulation Intl., p. 243, vol. 85, (2009). Published,

H. Wu, R. M. Fujimoto, G. F. Riley, M. Hunter, "Spatial Propagation of Information in Vehicular Networks", IEEE Transactions on Vehicular Technology, p. 420, vol. 58, (2009). Published,

Books or Other One-time Publications**Web/Internet Site****Other Specific Products****Contributions****Contributions within Discipline:**

Our finding is contributing to areas of computing concerning distributed simulation by defining a new paradigm (ad hoc distributed simulations) for creating distributed simulation programs, motivated by transportation system applications. If successful, this could lead to new research directions for that field in the area of distributed, on-line simulations.

Our work is also moving the transportation field in new directions by defining a new approach to using simulations to manage and optimize transportation systems. Our approach is a significant departure from existing approaches which rely largely on centralized solutions.

Contributions to Other Disciplines:

We believe the notion of ad hoc distributed simulations has application to a variety of other fields besides transportation. For example, we believe this concept could be applied to the management of large communication networks or in logistics, e.g., supply chain management. To test this hypothesis, we have conducted preliminary investigations on the applicability of ad hoc distributed simulations to modeling queueing networks, and have obtained good initial, positive results.

Contributions to Human Resource Development:

The project funded four Ph.D. students and four master's student. One of these PhD students and three of the master's students have graduated, and it is expected the remaining students remain in good standing in their respective degree programs.

Further, our outreach efforts to minority and women students has the potential of increasing the number of minority students that pursue advanced degrees in computing and transportation system engineering.

Contributions to Resources for Research and Education:

Trace data generated from this project has been made available to other researchers studying wireless vehicular networks.

Contributions Beyond Science and Engineering:

Technology transfer efforts under a recently funded Georgia Department of Transportation project have the potential to have broader impacts beyond the science and engineering community.

Conference Proceedings**Categories for which nothing is reported:**

Any Book
Any Web/Internet Site
Any Product
Any Conference

Project Findings

Project findings to date are primarily concerning the ad hoc distributed simulation concept, and real-time dynamic data analysis research. The principal findings are summarized below.

1 Ad Hoc Distributed Simulations

Ad hoc distributed simulations are on-line simulation programs, meaning they are able to capture the current state of the system through measurement, and then execute forward as rapidly as possible to project a future state of the system. By assumption, each of the simulators making up the distributed simulation can simulate some portion of the system faster than real time.

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Project Activities

1 Introduction

The Vehicle-Infrastructure Integration (VII) initiative by government agencies and private companies is deploying a variety of roadside and mobile sensing platforms capable of collecting and transmitting transportation data. With the ongoing deployment of vehicle and roadside sensor networks, transportation planners and engineers have the opportunity to explore new approaches to managing surface transportation systems, offering the potential to allow the creation of more robust, efficient transportation infrastructures than was possible previously. Effective and efficient system management will require real-time determinations as to which data should be monitored, and at what resolutions. Distributed simulations offer the ability to predict future system states for use in optimizing system behaviors both in day-to-day traffic conditions as well as in times of emergency, e.g., under evacuation scenarios. Data collection, data processing, data analysis, and simulations performed by system agents (sub-network monitoring systems, base stations, vehicles, etc.) will lessen communication bandwidth requirements and harness surplus computing capacity. Middleware to manage the distributed network, synchronize data and results among autonomous agents, and resolve simulation output conflicts between agents using disparate data sets become critical activities in such a system. Dynamic, data-driven application systems (DDDAS) offer the potential to yield improved efficiencies in the system that can reduce traffic delays and congestion, pollution, and ultimately, save lives during times of crisis.

We are addressing this challenge through a distributed computing and simulation approach that exploits in-vehicle computing and communication capabilities, coupled with infrastructure-based deployments of sensors and computing capabilities. Specifically, we envision a system architecture that includes in-vehicle computing systems, roadside compute servers (e.g., embedded in traffic signal controllers) as well as servers residing in traffic management centers (TMCs).

Our research activities over the past year focus on four closely coupled areas of research:

- Ad Hoc distributed simulations
- Simulation model development
- Data analysis
- Data dissemination

2 Ad Hoc Distributed Simulations

Consider a collection of in-vehicle simulations that are interconnected via wireless links and (possibly) wired network infrastructure. Individually, each simulation only models a portion of the traffic network – that which is of immediate interest to the “owner” of the simulator, Figure 1.

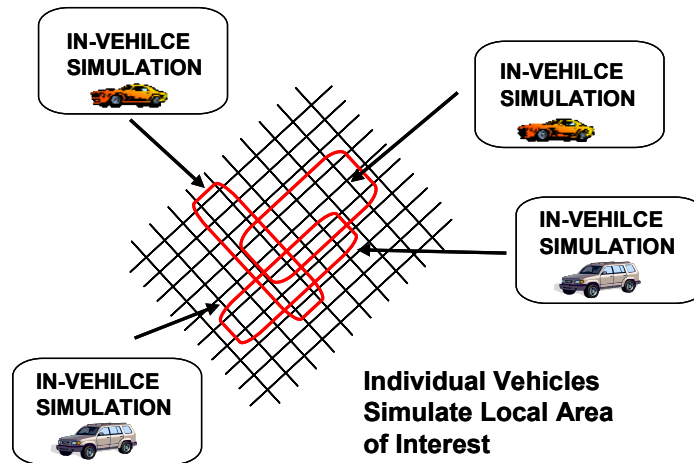


Figure 1: In-Vehicle Simulation

Collectively, these simulations could be used to create a kind of distributed simulation system with the ability to make forecasts concerning the entire transportation infrastructure as a whole. One can envision combining in-vehicle simulators with simulations running within the roadside infrastructure, e.g., within traffic signal controller cabinets, simulations combining sub-regions of the transportation network, and simulations running in traffic management centers to create a large-scale model of a city's transportation system, Figure 2.

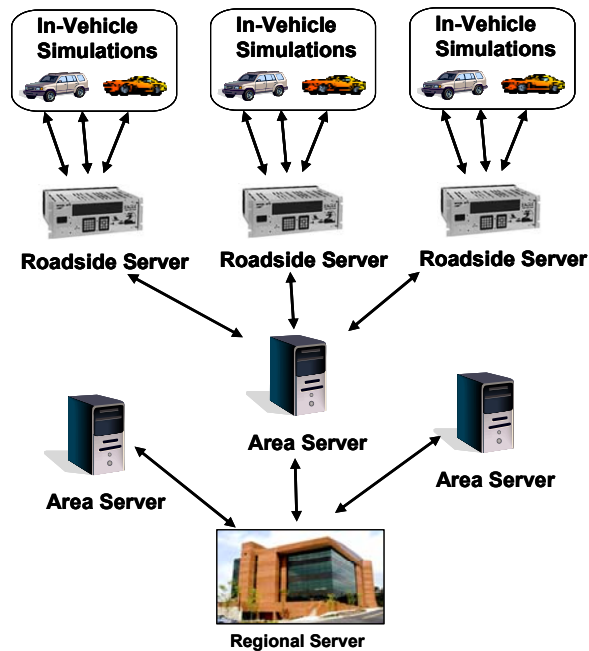


Figure 2: Ad Hoc Distributed Simulation Structure

We term a collection of autonomous, interacting simulations tied together in this fashion an *ad hoc distributed simulation*. Like a conventional distributed simulation, each simulator within an ad hoc distributed simulation models a portion of the overall system, and simulators exchange time stamped state information to collectively create a model of the overall system. However, in a conventional distributed simulation the system being modeled is designed in a *top-down* fashion. Specifically, the system is neatly partitioned into non-overlapping elements, e.g., geographic regions, and a logical process is assigned to model each element. By contrast, an ad hoc distributed simulation is created in a *bottom-up* fashion with no overarching intelligence governing the partitioning and mapping of the system to logical processes. Rather, the distributed simulation is constructed in an “ad hoc” fashion, in much the same way an arbitrary collection of mobile radios join together to form an ad hoc wireless network. The elements of the physical system modeled by different simulators in an ad hoc distributed simulation may overlap, leading to possibly many duplicate models of portions of the system, as seen in Figure 1. Other parts of the system may not be modeled at all. For example, an in-vehicle transportation simulator may be only modeling the portion of the road network along the vehicle’s intended path to reach its destination. Thus, ad hoc distributed simulations differ in important fundamental ways from conventional distributed simulations.

3 Transportation Simulation Models

An ad hoc transportation simulation based on a cellular automata model was developed for our initial investigations. The simulation consists of agents modeling vehicles, traffic signal controllers and traffic lights. The simulation operates in a timestep fashion. At every timestep, each agent decides what operation to perform next based on its own characteristics and the state of the system at the end of previous interval. Each vehicle agent includes characteristics such as origin, destination, maximum speed of the vehicle, and driver characteristics such as aggressiveness. Each vehicle has complete knowledge of the road topography around it. At the end of each timestep each vehicle agent makes decisions whether to move, stop, accelerate, or decelerate based on the following four rules:

- *Acceleration*: if the velocity v of a vehicle is lower than max velocity and if the distance to the next car ahead is larger than $v + \text{gap}$, the speed is increased: $v = v + \text{acceleration}$.
- *Slowing down* (due to other cars): If a vehicle at site X sees the next vehicle at site $X + j$ (with $j < v$), it reduces its speed to j : $v = j$
- *Randomization*: The velocity a vehicle, if greater than zero, is decreased with probability p_{dec} : $v = v - \text{deceleration}$.
- *Car motion*: each vehicle is advanced v cells.

Similarly, the traffic controller may also change its state, specifically the stop-go flag, at the end of each time step.

While the cellular automata simulation model allowed for the development of an understanding of the behavior of the ad hoc distributed approach it is desirable that future experimentation be conducted with a significantly more detailed, robust transportation simulation model. Further, the ability to adapt existing commercial simulation software for use in ad hoc distributed simulations would significantly improve the likelihood that

the technology would be used. An initial investigation into implementing the ad hoc strategy using the off-the-shelf transportation simulation model VISSIM was conducted. VISSIM is widely used by private firms and public agencies for transportation system analysis. VISSIM is a discrete, stochastic, time step based microscopic simulation model developed to model urban traffic (freeway and arterial) and public transit operations. The model is capable of simulating a diverse set transportation network features, such as facility types, traffic control mechanism, vehicle and driver types, etc. Individual vehicles are modeled in VISSIM using a psycho-physical driver behavior model developed by Wiedemann. The underlying concept of the model is the assumption that a driver can be in one of four driving modes: free driving, approaching, following, or braking. VISSIM version 4.10 was utilized for this investigation.

4 Real-Time Dynamic Data Analysis

The precision of the real-time data varies depending on the level of data aggregation. For example, minute-by-minute data are more precise than hourly average data. We examined the creation of an accurate estimate of the evolving state of a transportation system using real-time roadway data aggregated at various update intervals.

Using the VISSIM model described in the previous section, a simulation of the transportation network in the vicinity of the Georgia Institute of Technology in Atlanta, Georgia was utilized to represent the real world, with flow data from the Georgia Tech model provided to a smaller simulation of two intersections within the network. The “real-world” flow data (i.e. flow data measured from the large scale Georgia Tech model) was aggregated in different intervals and used to dynamically drive the two-intersection model. The desire of this study was to explore how well the small-scale simulation model is able to reflect the real world scenario when fed data at different aggregation levels. This work explored congested and non-congested traffic demand at data five different aggregation time intervals: 1 sec., 10 sec., 30 sec., 60 sec., and 300 sec.

5 Data Dissemination

The proposed DDDAS system relies on mobile, wireless ad hoc networks to interconnect sensors, simulations, and servers. The experiments reported earlier were conducted over a local area network, and thus do not take into account the performance of the wireless network. However, the performance of the network infrastructure can play an important role in determining the overall effectiveness of the ad hoc distributed simulation approach. Thus, a separate effort has been devoted to examining the question of the impact of network performance on the results produced by the ad hoc distributed simulation.

Clearly, a single hop wireless link between the vehicles and servers severely limits the wireless coverage area, motivating the use of a multihop network. However, standard routing protocols designed for end-to-end communication in mobile ad hoc networks cause each node to maintain the state of their neighboring nodes, for efficient routing decisions. Such a solution does not scale to vehicular networks, where the nodes are highly mobile, and route maintenance becomes expensive. Other routing protocols such as those discussed in the literature attempt to address this problem using flooding or optimistic forwarding techniques.

Vehicle ad hoc network (VANET) data dissemination protocols are typically designed to address data sharing among the vehicles, and related applications such as multimedia, control data, etc. Distributed simulations, however, define a different data transfer model, and consequently, the solutions designed for data sharing applications may not perform well when transposed to the demands of simulations. Additionally, data transfers in VANETs is inherently unreliable, and drops and delays in message delivery can be highly dependent on factors such as traffic density and wireless activity, thus having a strong impact on the simulation itself.

To address this challenge, a data dissemination framework for addressing the routing demands of a distributed simulation in the VANET environment has been developed. Our framework uses a combination of geographic routing and controlled flooding to deliver messages, with no organization enforced among the vehicles. The design parameters of the framework are currently under study in order to assess how this impacts the overall accuracy and reliability of simulation results.